Decomposing of Cardiac and Respiratory Signals from Electrical Bio-impedance Data Using Filtering Method

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Abstract— **This paper presents an attempt to decompose cardiac and respiratory signals from an electrical bio-impedance (EBI) dataset. To accomplish this task, the conventional filtering method is used. FIR (low pass filter (LPF) and high pass filter (HPF)) was intended to decompose the impedance respirogram (IRG) and impedance cardiogram (ICG), (the clean ECG was also extracted by filtering method). The decomposed components can be analysed and processed further, each one separately. Investigation was accomplished under the assumption that the total EBI dataset is the summation of cardiac and respiratory components, motion artefacts, stochastic disturbance and noise. The impedances were measured using a Zurich Instruments HF2IS Impedance Spectroscope. A sixteen electrodes configuration belt was used around a human thorax, to measure the EBI. This study showed that it is not possible to decompose cardiac and respiratory signals completely through conventional filtering method.**

Keywords— **Cardiac Signal, Electrical Bio-impedance; FIR Filter; Respiratory Signal.**

I. INTRODUCTION

This study is focused on the decomposition of cardiac and respiratory components from a mixed electrical bio-impedance (EBI) raw dataset, by suppressing disturbing components such as motion artefacts, stochastic disturbance and noise by filtering.

By means of EBI measurements one can assess physiological activities and structural configurations of a tissue, as well as offer possibility to analyze dynamic processes in organs such as a) impedance cardiogram (ICG) of the heart, and b) impedance respirogram (IRG) from the thorax. The EBI measurement is a non-invasive and cost effective method.

The assumption is that, the total EBI data is the sum of:

$$S(t) = S_{car(t)} + S_{resp(t)} + N_{mot(t)} + M_{stoch} + S_{bas(t)} \quad (1)$$

where $S_{car(t)}$ and $S_{resp(t)}$ are the cardiac and respiratory components, $N_{mot(t)}$ unwanted motion artifact caused by body movement or muscle activity, M_{stoch} stochastic disturbance and $S_{bas(t)}$ basal (average) signals.

The cardiac and respiration components are correlated due to their nature [1]. However, they can be viewed as uncorrelated under the assumption that the correlation is relatively weak because both components have different sources [2]. The filtering method was tested as a mean for accomplishing a) ICG and IRG from the total EBI dataset and b) simultaneously suppressing the artefacts.

II. ELECTRICAL BIO-IMPEDANCE (EBI)

The study of the EBI is very important in the medicine to developed robust, efficient and practical measurement apparatus, which can be based on the electrical bio-impedance [1, 3]. The signal processing area has acquired promising achievements which help to estimate components of the EBI and to further analyze and process them. Impedance devices with digital signal processing capability can be used to estimate and analyze the EBI components efficiently, precisely, reliably and online with the measurements.

The measurement of EBI is a scientifically relevant topic nowadays. The prefix bio in the electrical bio-impedance is due to the biological essence of an object [3]. In addition to galvanic path, the EBI measures dielectric polarization on a tissue, which arises from intrinsic polarizability, which is the manner that the biological tissue resists to an electrical current.

In a typical impedance measurement setup, a known current is supplied on the tissue under test. The EBI measures the dielectric response of the tissue under examination [3].

The EBI measurement is used to get an input dataset to which the filtering method was applied in this study.

The EBI is measured by applying electrical current across the thorax region and measuring the voltage drop (Figure 1).

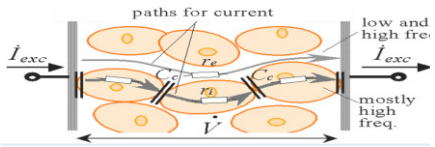

Fig. 1 Schematic of the high and low frequency current distribution in a cell tissue [5].

At a selected frequency, the EBI can be expressed as the ratio of the voltage drop to the excitation current, which has caused the voltage drop [4]:

$$\dot{Z} = \frac{V}{I} \quad (2)$$

where V is the voltage drop which measures the resistance, and I is the electrical current, which is used to excite the tissue.

It has become clear that the EBI on living tissue is frequency dependent because of the capacitive effect of tissue. In addition, each tissue region and even each cell has different dielectric response as well as spectral characteristics in the frequency domain.

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The cardiac and respiratory components from the human thorax can be measured as the time variation of the EBI. From the total EBI, the useful components, like cardiac and respiratory ones, can be extracted for further analysis and separate processing [4].

III. EBI MEASUREMENT PROCEDURE

The dataset of the total EBI is measured using multiple pairs of electrodes. The excitation current was applied to the body through one pair of electrodes. The voltage drop was measured though the other pairs of electrodes.

The EBI measurement setup is depicted in Figure 2. Such kind of electrodes' setup is assumed, allow to produce strong enough variations of the EBI in order to measure the cardiac and respiration activities, which are caused by heart and lungs.

A. Configuration of Electrodes

The sixteen electrodes configuration was used in the experiment, which was performed in the Thomas Johan Seebeck Department of Electronics, at Tallinn University of Technology. The electrodes were positioned at 6 cm distance from each other. This belt was worn around a person's thorax. Figure 2 illustrates the configuration of electrodes.

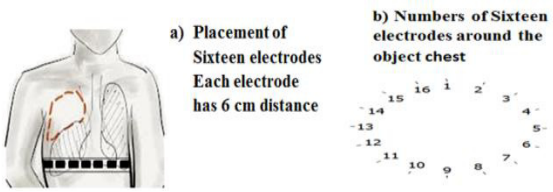

Fig. 2 Sixteen electrodes configured belt, which is used at the EBI measurement procedure.

The impedances were measured using a Zurich Instruments HF2IS Impedance Spectroscope.

Current source excitations, of 8 slightly different frequencies, were used in every electrode pairs in order to minimize mutual influence of simultaneous impedance measurements between the channels.

The measurement current was confined under 1mA at all times for ensuring patient's safety. Electrical contact to the thorax was achieved by 3M disposable surface EMG/ECG silver/silver chloride electrodes, followed by proprietary front-end electronics close to the electrodes.

B. Pre-processing of Data Gathering Experiment

A person was instructed at the beginning of the experiment to hold his breathing around 10s (from 1s to 10s), after the 10th second he starts to take deep breathing around 10s (from 10s to 20s) and finally, while taking the breathing, added motion artefacts around 10s (from 20s to 30s).

According to this, the total EBI dataset was divided into three different segments. Each segment contained 10 sec of the total EBI raw data, about 10,000 samples. Accordingly the structure of each segment is as follows:

a) only cardiac,
b) cardiac + respiration,
c) cardiac + respiration + motion artefacts.

IV. FINITE IMPULSE RESPONSE (FIR) FILTERS

The FIR filters are assure to be stable BIBO and generally used in applications that require the filter to have linear phase frequency response to the desired signal passed [6]. Types of FIR filters are the LPF, HPF and BPF. These filters are used in this study to filter out the IRG and ICG signals.

The LPF is a filter that allows the harmonic components of low frequencies up to cut-off (fc) to pass and attenuates all components of higher frequencies [7]. The LPF is used to filter out the IRG component which has low frequency, and to attenuate all higher frequencies, because respiration can take place only at low frequency range often below 1 Hz.

The HPF is a filter that allows the harmonic components of high frequencies above the fc and attenuates all components of lower frequencies [7]. The HPF is used to filter out the ICG. Fc frequency is selected to attenuate all lower frequencies because those are out of interest.

V. FILTERING METHOD

The decomposition of cardiac and respiratory components was accomplished from Segment (b) of the total EBI dataset. We assume that the total EBI dataset is the summation, as shown in Equation 1.

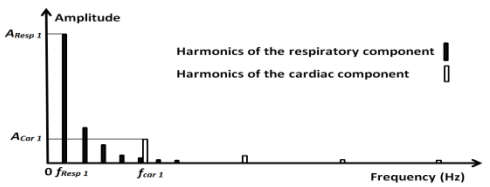

Fig. 3 An example of frequency spectrum of EBI, which contains cardiac and respiratory components. [4].

The heart rate S_{car} (Eq.1) of a healthy person can vary in the range between 60 bpm to 240 bpm (1 to 4 Hz) [8], and the respiration rate S_{resp} (Eq.1) of a healthy person can vary from 12 breaths/min to 30 breaths/min (0.2 to 0.5 Hz). Unfortunately, muscular activities also lie on almost on the same frequency

range, and the higher harmonics of the respiratory signal also lie on the same frequency range with the cardiac signal [8 - 9]. The harmonic spectrum of EBI signal is shown in Figure 3.

The waveform of the cardiac and respiratory components of the EBI signal are relatively smooth [10] and that is why only few higher harmonics are required for representing them.

In this study, LPF and HPF were used to extract the impedance respirogram (IRG) and impedance cardiogram (ICG) from the total EBI dataset (Segment b). The electrical cardiograph (ECG) was also filtered separately as a reference signal for ICG.

In accordance with the characteristics of the signals, given above to separate the respiratory and cardiac signals, a structure of filtering device, given in the block diagram in Figure 4 was used.

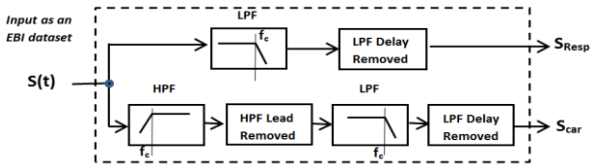

Fig. 4 Flow diagram of the filtering method

To filter out the ICG waveform, the HPF is used to attenuate the lower frequencies, mainly to suppress the respiration components, and the LPF is used to attenuate the higher frequencies, which are out of interest. The Equation (3) is used to determine the high pass and low pass FIR filters delay:

$$\mathrm{td} = \frac{\mathrm{N\text{-}1}}{2}, \tag{3}$$

where N is the number of filter coefficients and td is the time delay.

VI. Results

The filtering method according to Figure 4 was used to decompose the cardiac and respiratory components from the total EBI, and simultaneously to suppress the stochastic disturbance, motion artefacts and noise.

A. Decomposition of the IRG

The IRG component contains harmonics with low frequencies of relatively high amplitudes (Figure 3). On the basis of spectrum analysis, the LPF was designed to filter out the IRG component. For IRG, the pass-band was set to 1.5 Hz and attenuation of higher frequencies was set to 80 dB. Figure 5 (dotted line, blue colour) and Figure 6 (a) show the decomposed IRG signal from the total EBI dataset. To some extent, cleaner IRG signal is extracted, and it is slightly smoother as well.

B. Decomposition of the ICG

The cardiac component contains low amplitude harmonics at relatively higher frequencies. The spectra of cardiac and respiration signals often overlap with each other (Figure 3). Based on spectrum analysis, the LPF was designed and tuned to separate the ICG component. For the ICG, the pass-band was set to 20 Hz, stop-band was set 22 Hz and attenuation of all higher frequencies was set to 80 dB.

Figure 5 (solid line, red colour) and Figure 6 (b), shows the separate output ICG signal. The ICG signal is corrupted by the respiration: because respiration has high influence, we just can see the rippling. The LPF permits all low frequency components to pass. Accordingly the respiration components, which exist at low frequencies, will also pass (Figure 3).

In order to decompose just cardiac components, first a HPF was designed to attenuate the low frequencies of the respiration component. After attenuating the low frequencies, the LPF was designed to attenuate the higher frequencies; i.e only passed the range of interest. This is shown in the flow diagram of the filtering method in Figure 4.

The Figure 5 (solid line, black colour) and Figure 6 (c) shows the filtered ICG signal which is extracted from the total EBI dataset; but the extracted ICG signal is not clean enough. It contains some noise.

The first harmonic of the cardiac component is very close to some of the higher respiration harmonics (Figure 3). In order to suppress the respiratory component, the cut-off frequency of the HPF was taken closer to the first cardiac harmonic. It was 0.8 Hz.

C. Decomposition of the ECG

The electrical cardiogram (ECG) was recorded during the experiment, and added to the total EBI dataset. The ECG is included in this study as a reference signal for ICG.

Based on the spectrum analysis, the LPF was designed to clean the ECG component. For the ECG, the pass-band was set to 25 Hz and stop-band was set 30 Hz, and attenuation the all higher frequencies set to 80 dB.

Figure 5 (dotted line, green colour) and Figure 6 (d), show the cleaned ECG signal. To the some extent the ECG signal is clean.

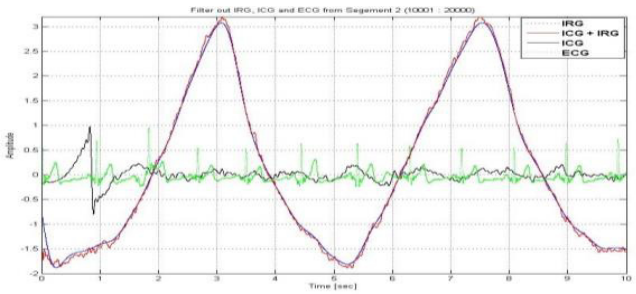

Fig. 5 Filter out the signals (IRG and ICG) from the total electrical bio-impedance (EBI) dataset on the same scale.
a) Impedance Respirogram (IRG),
b) Impedance Cardiogram (ICG) corrupted by respiration,
c) Impedance Cardiogram (ICG),
d) Electrical Cardiogram (ECG)

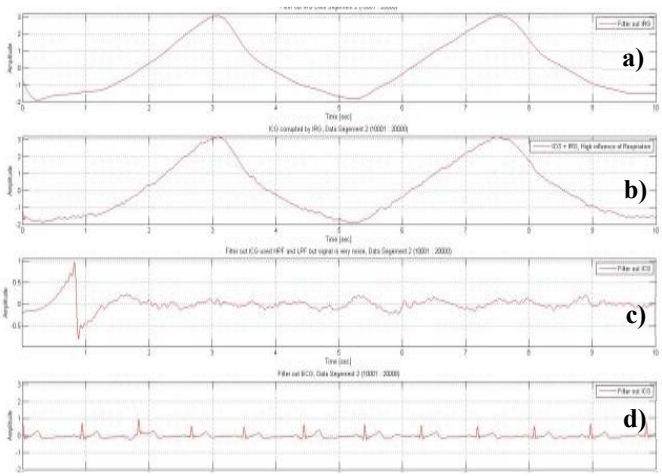

Fig. 6 Filter out the signals (IRG and ICG) from the total electrical bio-impedance (EBI) dataset.
a) Impedance Respirogram (IRG),
b) Impedance Cardiogram (ICG) corrupted by respiration,
c) Impedance Cardiogram (ICG),
d) Electrical cardiogram (ECG)

VII. DISCUSSIONS, CONCLUSIONS AND FUTURE WORK

The first LPF, which was designed to separate out the IRG signal and attenuate the higher frequencies because respiration (IRG) exists at low frequencies, to some extent separated the IRG signal, which became smoother and cleaner. The results are shown in Figure 5 (dotted line, blue colour) and Figure 6 (a).

The second LPF was used to separate the ICG signal. In Figure 5 (solid line, red colour) and Figure 6 (b) are shown the separated ICG signal. The results seem to be corrupted by respiration because respiration has influence to the ICG through its higher harmonics.

In order to filter out the cardiac component, the HPF was designed and tuned to attenuate the low frequencies first those frequencies which are out of interest. We again applied a LPF to attenuate the higher frequencies; those which are also out of interest. Figure 5 (solid line, black colour) and Figure 6 (c) are shown the ICG signal, which is separated. The ICG is not clean enough, it contains some noise.

The ECG was extracted to use as a reference signal for the ICG. The LPF was designed to separate the clean ECG component. Figure 5 (dotted line, green colour) and Figure 6 (d) is shown the decomposed ECG signal. At the some extent the ECG signal is very clean.

It seems that it is difficult to solve the decomposition problem through conventional filtering method. The filtering method could be used as pre-processing for the total EBI. Further development of the method is required to approach better decomposition of the cardiac and respiration signals from the total EBI dataset. For example, one could try to take the advantage of blind source separation (BSS) because BSS works on correlated and dependent sources. The cardiac (S_{car}) and respiratory (S_{resp}) components are correlated. Moreover, machine learning techniques could be used to approach the problem.

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